NASA Technical Memorandum 100439

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SUMMARY

This paper traces flight research and testing from its modern establishment during the Wright brothers era to the present. Methods developed to test unproven concepts, solve problems encountered and measure results are discussed.

INTRODUCTION

Flight research and flight testing form a critical link in the aeronautics research and development chain. Brilliant concepts, elegant theories, and even sophisticated ground tests of flight vehicles are not sufficient to prove beyond a reasonable doubt that an unproven aeronautical concept will actually work and perform as predicted. Flight research and testing provide the ultimate proof that an idea or concept performs as expected. Ever since the Wright Brothers, flight research and testing have been the crucible in which aeronautical concepts have advanced and been proven to the point that engineers and companies have been willing to stake their future to design and produce new aircraft. That is still true today, as shown by the development of the experimental X-30 aerospace plane.

As modern aircraft have become more sophisticated and complex, flight research has become increasingly important as a way to validate both overall aeronautical concepts and individual technology experiments. This has required that new approaches to flight research be developed that range from experimental construction techniques, advanced instrumentation and computer-controlled maneuvers to new real-time and postflight analysis and display techniques. The development of high-speed, large capacity computers has paved the way for the emergence of computational fluid dynamics (CFD) as a tool for the aircraft conceptual design process. For these CFD tools to be useful it is critical that the fluid dynamic models be validated in a realistic environment. This has also pushed the development of new wind tunnels and associated test techniques; but the final validation still requires the design of carefully formulated flight research programs and experiments to provide the kind of comprehensive data that is required for code validation. There is still much flight research to be done to develop and provide the data that adequately describe a maneuvering airplane in a dynamic, nonstandard atmosphere for validation of both CFD and ground test techniques.

The Dryden Flight Research Facility of NASA Ames Research Center (Ames-Dryden) continues to be involved in a number of flight research programs that require understanding and characterization of the total airplane in all the aeronautical disciplines, for example the X-29. Other programs such as the F-14 variable-sweep transition flight experiment have focused on a single concept or discipline. Ames-Dryden also continues to conduct flight and ground-based experiments to improve and expand the ability to test and evaluate advanced aeronautical concepts. A review of significant aeronautical flight research programs and experiments is presented here to illustrate both the progress being made and the challenges to come.

FLIGHT RESEARCH

Historically, flight research has played a pivitol role in the advancement of aeronautical science and technology. Indeed, it was the flight research with gliders (Fig. 1) that led the Wright brothers to the discovery that the camber of 1 to 12 recommended by Otto Lilienthal was not as good as the camber of 1 to 22 that the Wrights used in one of their designs. The Wrights also discovered in flight that the center of pressure on a cambered surface moved aft as angle of attack is reduced at low angles of attack, which is opposite to the center of pressure movement on a plane surface. This led, of course, to the construction of their wind tunnel so they could acquire data that allowed them to design the first successful self-powered airplane (Kelly, 1882).

One of the first projects completed by the executive committe of the National Advisory Committee for Aeronautics (NACA) in 1915 was a facilities survey of industry, government, and universities. Out of that work, it was concluded that NACA would require both a laboratory and a flight test facility. This led to the establishment of the Langley Memorial Aeronautical Laboratory in 1917. The two-pronged approach to aeronautical problems at Langley—model tests and full scale flight tests—established the interdependence of these two test disciplines (Hansen, 1987). Emphasis on this dual approach has been strong ever since and is today a cornerstone of the NASA aeronautics program.

The loss of a Lockheed P-38 Lightning and the pilot during a dive test early in World War II focused the need for a more complete understanding of the essential characteristics of transonic flight. Because of an inability of current wind tunnels to operate and produce reliable data in the transonic speed range, Robert Gilruth, a NACA engineer devised a method of conducting transonic research. He had observed that significant supersonic flow existed on the top of a North American P-51 wing during dives, even though the aircraft speed was only approximately Mach 0.75. As the first application of the wing-flow technique, a small airfoil model was mounted perpendicular to the P-51 wing upper surface similar to that shown in figure 2. Subsequently, many other airfoils were tested, and this technique provided the most systematic and continuous plots of transonic data assembled by NACA at that time. This approach was used to experimentally confirm that thin wings were best for supersonic flight. The wing-flow technique was also the first experimental validation of R.T. Jones' theory which predicted that in transonic and supersonic flight the drag of a wing would be significantly reduced if it were swept (Hansen, 1987).

The research airplane was conceived by John Stack of Langley in 1933 when he designed an airplane which he used to assess the performance that was theoretically acheiveable (Hansen, 1987). In 1940 he began to have active discussions with NACA management and the military on the need for a research airplane that would provide the data necessary to understand the compressibility problems that the military airplanes were experiencing in high-speed dives. The golden era for experimental research airplanes began in 1944 when the Army Air Force undertook the development of an experimental rocket-powered aircraft, the Bell XS-1, which was designed to penetrate the "sonic barrier" (Fig. 3). At about the same time the Navy contracted with Douglas for the development of the turbojet-powered Douglas Model 558, high-speed test airplane designed to gather research data in the critical transonic speed range (Hansen, 1987). These were followed by the X-2, X-3, X-4, X-5, and the XF-92A. The Bell XS-1 met it's objective of achieving supersonic flight on October 14, 1947 with Captain Chuck Yeager at the controls in the skies over the California desert. The X-2 also was dedicated to solving the problems of supersonic flight, while the other aircraft were designed to investigate advantages and problems with new configurations. The Douglas X-3 had a low-aspect-ratio thin wing; the Douglas D-558-2 had swept wings; the Northrop X-4 was semitailless; the Bell X-5 had variable sweep wings; and the Convair XF-92A was designed with a delta wing (Hallion, 1984).

By 1954 it became apparent that the problems and challenges of hypersonic flight could best be addressed through the development and flight test of a manned Mach 7 research aircraft. The Air Force, Navy, and NACA signed a Memorandum of Understanding establishing a Research Airplane Committee to provide the technical direction necessary to develop and test the X-15 airplane (Fig. 4). The program was designed to assess the problems and develop solutions associated with hypersonic flight such as structural design, aerodynamic heating and heat transfer, energy management and the transition from the reaction controls used in space to the aerodynamic controls used in the atmosphere. The X-15 was the most successful research airplane program ever undertaken as shown by the 199 flights accomplished in just over nine years. Until the first orbital flight of the space shuttle Columbia in 1981, the X-15 held the altitude and speed records for winged aircraft, with flights as high as 67 miles and a maximum speed of Mach 6.7. The knowledge and experience gained in the X-15 program led directly to the systems and techniques used in the space shuttle (Hallion, 1984).

As NASA moved into the space age in the early 1960s, it became apparent that lifting reentry spacecraft would be much more useful than ballistic capsule craft in that they could maneuver in the atmosphere land horizontally on the earth at a predetermined location. A series of lifting body concepts were developed at NASA Langley, NASA Ames, and under contract to the Air Force that culminated in the development and flight test of several designs (Fig. 5). The vehicles were designed to use rocket propulsion to boost them to the Mach 3 speed regime, at which time the rockets would be turned off and they would glide back to an unpowered landing at Edwards. All the craft had a very low lift-to-drag ratio and therefore decended very rapidly. The need to know and monitor the kenetic and potential energy state of these vehicles in real time in order that decisions on landing locations could be made in case of an emergency, further developed and refined the energy management concepts that were initially started for the X-15 program. The primary research objectives for these vehicles centered around the flying qualities issues associated with essentially wingless craft in the critical landing phase and in the transonic speed range where vehicle characteristics are typically less well-defined in ground tests. The successful completion of this program with the successful runway landing series of the Martin X-24B (Figure 6) provided the confidence that the space shuttle could indeed re-enter from space unpowered and land precisely at a predetermined location by carefully managing the total vehicle energy. The ability to land unpowered was critical to the success of the Shuttle progam since a large weight penalty would be incurred at launch if air-breathing engines were required to land the vehicle (Hallion, 1984).

Even with this extensive base of data and knowledge of the flying qualities of lifting bodies, the need for flight test and research was amply demonstrated during the shuttle approach and landing tests (ALT) program (Fig. 7) when pilot-induced oscillation (PIO) tendencies were exhibited by the shuttle on its first concrete runway landing. Researchers at NASA Ames-Dryden then accepted the challenge to develop modifications to the shuttle control system that would suppress any PIO tendencies during the critical approach and landing phase of flight. A PIO suppressor was developed using the Dryden shuttle simulation, and it was then verified in flight using the F-8 digital fly-by-wire aircraft (to be described later). Because of the potential problems associated with pilot-induced oscillations and the convincing demonstration of a reasonable and cost-effective solution, the PIO suppressor was incorporated into the shuttle flight control system prior to the first orbital flight and subsequent landing.

The late 1960s and early 1970s brought a resurgence of interest in the problems associated with supersonic flight, principally those impeding the development of an efficient, economically viable and environmentally compatable supersonic transport. A flight research program was initiated using the North American XB-70 aircraft (Fig. 8) to acquire supersonic cruise data. This aircraft was used in an extensive program to acquire data to assist in the development and validation of computer codes to predict the sonic boom overpressure signature characteristics of large, high-flying supersonic aircraft. In addition, studies of flying qualities were conducted at both supersonic speeds and during landing approach, as well as experiments to characterize boundary layer noise and the aeroelastic response of large aircraft to gusts. This program provided valuable insight into and developed solutions to some of the problems associated with high altitude, high-speed cruise flight.

The Lockheed YF-12A and YF-12C aircraft (Fig. 9) were loaned to NASA to conduct research in propulsion, structures, and flight dynamics at supersonic cruise flight conditions. One particularly difficult problem was to assess the relative contributions of aerodynamic and thermal loads imposed on the aircraft structure at Mach 3 cruise conditions. Extensive data acquired in flight from a heavily instrumented YF-12A, in conjunction with data acquired from heating a complete airplane in the Ames-Dryden Flight Loads Research Facility, allowed the aerodynamic and thermal load contributions to be separated. The YF-12C was instrumented for propulsion system measurements and the program yielded such surprising results as the fact that the inlet bypass system provided more yaw power at cruise than the aircraft rudders and that the mixed compression inlets were producing more than one-half the total propulsive thrust at Mach 3.2. Flight dynamics problems encountered in the XB-70 program also surfaced. Flying through local pressure and temperature variations at high speed cause variations in speed (because Mach number is a function of pressure and temperature) with subsequent changes imposed on the aircraft attitude by the autopilot, which resulted in altitude variations of several thousand feet. This problem was successfully overcome by integrating the control of the propulsion and flight control system. An unexpected benefit of this control integration was an aircraft range increase of 7 percent. This technology was incorporated in the operational SR-71 fleet several years ago as a result of the NASA flight research program.

Flight research and test have long been the preferred way to prove new aerodynamic concepts or configurations. Concepts that improve vehicle performance in the transonic speed range have routinely been validated in flight because of the difficulty in making accurate and precise measurements in wind tunnels at transonic speeds. One of the proof-of-concept programs that was very successful was the application of Dr. Richard Whitcomb's supercritical wing concept to a Vought F-8A aircraft (Fig. 10). This aircraft was chosen because the wing could be easily removed and replaced with a new design, the landing gear retracted into the fuselage, not the wing, and because the F-8 had supersonic speed capability. The concept did indeed improve the transonic efficiency of the F-8 by as much as 15 percent and was widely accepted, as shown by the numerous commericial and military aircraft produced with supercritical airfoils. This program was a model for cooperation between the wind tunnel and flight research community, and indeed provided very good correlation between the wind tunnel and flight results.

As new aircraft were designed to achieve higher and higher levels of performance, it became increasingly difficult to design hydromechanical flight control systems that were light-weight, survivable, and with adequate levels of redundancy to assure that the aircraft would not be lost due to control system malfunctions. Electronic controls and especially digital electronic controls seemed to be the cure for many of the problems. In the early 1970's, Ames-Dryden embarked on a flight research program using a modified Vought F-8C (Fig. 11) to identify problems associated with digital flight controls and to assess the postulated benefits. When the aircraft first flew in 1972, it marked the first time a manned aircraft had flown with a digital flight control system with no mechanical backup. The program progressed in two phases, with the first one using modified Apollo computers to control flight, while the second phase involved the development and flight test of a new triplex computer system. This progam was a technology pacesetter, as shown by the wide-spread application of the technology to aircraft designed and produced subsequently. Another very important contribution from this program was the development of the processes and procedures necessary to verify and validate software and hardware for flight-critical systems. These approaches have been imitated and expanded upon by all the organizations that have successfully produced and flown digital flight control systems in manned airplanes.

One of the keys to obtaining significantly improved performance for subsonic transport aircraft is to reduce the drag by maintaining laminar flow over large portions of the wing and fuselage. Recent tests with F-14 aircraft (Fig.12) as a test bed have indicated that laminar flow is achievable naturally at transonic speeds on swept wings at representative sweep angles. Gloves of foam and fiberglas were fabricated and attached to the production F-14 wing with the section designed to provide a favorable pressure gradient over much of the wing chord. This was another example of the requirement and viability of conducting basic research on boundary-layer transition in flight. Only in flight is the researcher able to evaluate boundary-layer transition under realistic noise and natural turbulence levels at the design conditions. The flight environment also allows the experiment to be evaluated at off-design yet realistic flight conditions. Innovative instrumentation developments and low-cost glove fabrication techniques have been applied to acquire boundary-layer-transition data in flight and in the real atmosphere that is definitive and of laboratory quality. This flight experiment has provided critical data that prove the feasibility of constructing a swept-wing transport that can achieve considerable amounts of natural laminar flow with the attendant drag reductions and fuel economy, and it has provided the benchmark data from the flight environment for the validation of airfoil design and boundary-layer stability codes.

Another way which laminar flow can be achieved is by properly tailoring the pressure distribution and removing a small portion of the boundary layer near the airplane skin by sucking through slotted or porous skin. NASA JetStar airplane (Fig. 13) was used to demonstrate the effectiveness and reliability of laminar flow control under representative flight conditions by simultaneously testing alternative leading-edge flow control concepts on each wing. A spanwise section of the JetStar wing leading edge was modified to include laminar flow control, insect protection, and dicing capability. One leading-edge test article used a slotted skin, while the other test article used a porous skin. Both test articles were tested under rigorously controlled research flight conditions, and the airplane was operated at a number of commercial airports throughout the United States in representative airline operational environments, including winter and summer weather conditions. This program has demonstrated the effectiveness and reliability of leading-edge laminar flow control in a realistic environment for two different concepts (slots and porous skins) and has shown that while laminar flow is greatly reduced in clouds and ice particles, it immediately returns upon exiting the clouds.

As previously noted in the discussion on the YF-12 program, the integration of the propulsion and flight control system can provide significant improvements in airplane performance with minimum weight or cost penalties. An integrated flight and propulsion control system has been developed and flight demonstrated on a McDonnell F-15 aircraft (Fig. 14). The program was entitled highly integrated electronic control (HIDEC) and several different control modes were investigated. One mode, the advanced engine control system (ADECS), modulated the engine stall margin as a function of flight condition and engine state. It also anticipated dynamic maneuvers by using pilot stick inputs which were then traded off for increased thrust. Engine thrust was increased as much as 11 percent at subsonic flight conditions, resulting in significantly improved aircraft performance. Rate of climb was increased approximately 14 percent and constant-altitude acceleration at maximun power was increased by 24 percent. Other control modes have been implemented which greatly improve engine life by reducing engine tempatures while maintaining thrust, or reducing fuel usage while maintaining constant thrust. Integrated controls research in flight has been very effective since the the behavior of the integrated control system in a dynamic environment is critical to it's usefulness, and it has accelerated the acceptance and application of the technology as previously noted with respect to the operational SR-71 aircraft. The USAF has also incorporated the ADECS technology into their improved-performance F-110 and F-100 engines that power the advanced F-15 and F-16 aircraft.

The new aerodynamic concepts that are developed analytically and in ground facilities continue to require validation in the dynamic environment of flight, as shown by the advanced fighter technology integration (AFTI)/ F-111 mission adaptive wing program (Fig. 15). The performance benefits of a smooth variable-camber wing have been validated, and an advanced digital control system that optimizes aircraft performance throughout the flight envelope is being evaluated. Automatic performance-seeking control modes attempt to maximize the relevant performance parameter through an on-line control approach that couples the flight control and wing camber control systems to produce either an optimum cruise configuration or an optimum maneuvering configuration, while at the same time compensating for random gust inputs to the airplane. Results to date indicate that range improvements of 25 percent and increased sustained maneuver capability of 20 percent are achievable.

The Grumman X-29 airplane (Fig. 16), the first new experimental airplane in more than twelve years, has been exploring the performance and configuration advantages of the forward-swept-wing concept. At the same time, several other emerging technologies that were incorporated into the airplane have been tested and evaluated. These include relaxed static stability (−35 percent); three-surface longitudinal control; thin, supercritical, aeroelastically tailored composite wing; close-coupled wing and canard; and digital flight control system. The successful integration of these technologies and the performance benefits accruing from them have been demonstrated and are in the process of being correlated with predictions and wind tunnel test results. The X-29 program has required the development and application of new instrumentation and real-time analysis techniques in order to safely and efficiently expand the flight envelope. A new optical deflection measurement system was developed to accurately measure the wing deflection in flight for correlation with ground test results and to characterize the shape for aerodynamic correlations. New methods for extracting aerodynamic derivatives from highly unstable aircraft were developed, based on parameter estimation techniques. Ground-based methods for predicting the divergence of forward-swept wings had to be adapted for use in flight to assure the safe expansion of the flight envelope. Other real-time analyses have been developed and will be discussed later in this paper.

The NASA high-angle-of-attack program has recently focused on the F-18 configuration as representative of designs that can achieve high-angle-of-attack flight. The program consists of coordinated computational fluid dynamic analysis, simulation, wind tunnel testing, and flight research. Ames-Dryden has responsibility for conducting the flight research using a specially instrumented McDonnell F-18 aircraft (Fig. 17). The F-18 airplane features a long strake or leading edge extension (LEX) from the nose to the wing leading edge. These LEXs generate strong streamwise vortices at angle of attack, caused by the separated flow emanating from the sharp edges, which then roll up into a pair of vortices. This vortical action can have favorable effects by generating additional lift at moderate angles of attack, supplementing the lift of the wing. They can have unfavorable effects if the vortices burst near vertical tails or stabilizers and cause buffet on the structure. The initial flight research has been directed at characterizing the aerodynamic flows associated with the forebody and LEXs, both on the surface and off the surface of the airplane.

A smoke generator system has been installed in the airplane so that smoke can be injected into the vortex core at the apex of the LEX in order to make the vortex visible. These vortices have been photographed (Fig. 18) on the F-18 high-angle-of-attack research vehicle (HARV) using a remotely operated camera installed in the wingtip. The vortex burst is evident in the figure and is characterized by a rapid expansion of the core, coupled with a rapid deceleration of the axial velocity. The impingement of these vortices on tail surfaces have significant impact on the structural fatigue life of the tail structure, and methods for minimizing interaction of these vortices with the tails are being investigated.

At high angles of attack vortices are also generated on the upper surface of the forebody of the F-18. Previous studies have shown the existence of two primary and two secondary vortices. These vortices can be either symmetrical with respect to the nose or asymmetrical depending upon the angle of attack and nose apex angle. A system to visualize the surface flow of these forebody vortices has been installed on the F-18 HARV. Proplyene glycol monomethyl ether (PGME), a liquid, is mixed with dye and emitted out of surface orifices on the nosecone and forebody while flying. When the pilot has stabilized the airplane, the fluid is released and the airplane flight conditions are held constant for approximately one minute while the dye dries. The resulting dye patterns are then photographed on the ground after the flight. Presented in Fig.19 are the results of one test at an angle of attack of 30°, angle of sideslip 2°, and chord Reynolds number of 10,800,000. Where the streamlines flow together, a separation line has formed that indicates where the surface flow separates from the surface to form streamwise vortices. Secondary vortices of opposite rotation are induced by the primary vortices and the separation lines for both primary and secondary vortices are visible in the figure. When these vortices are symmetrical, the side forces on the forebody are small, but at higher angles of attack these vortices can become asymmetrical and produce significant side forces. At approximately 40° angle of attack the directional stability of the F-18 diminishes to near zero, and the airplane goes into a mild wing rock with the angle of sideslip varying from +14 to −7°. This is believed to be caused by the oscillatory nature of the asymmetric nose vortex shedding.

The F-18 HARV has produced some very dramatic results for correlation with wind tunnel and computational efforts and many challenges remain to provide the high-quality, detailed data necessary for a thorough understanding of the complex nonlinear flow phenomena that characterizes high angle-of-attack flight.

The development and application of new instrumentation, test, and analysis techniques is the lifeblood of any experimentally oriented organization, and flight research is no exception. The key to this activity is a core of experienced and innovative flight researchers working together with instrumentation development engineers and technicians. Several new approaches have already been highlighted in this paper, such as liquid crystals to detect transition, smoke generators for vortex visualization, and the optical deflection measurement system; however, much remains to be done. New methods for the analysis of flight data are also required to enhance flight safety and improve productivity. Two recent advances in this area include the ability to conduct flight control system dynamic stability analyses in real time and the ability to measure, compute, and display in real time the aircraft aeroperformance.

The design criteria for the statically highly unstable (up to −35 percent at certain flight conditions) forward-swept-wing configuration of the X-29 aircraft included minimum levels of gain and phase margins in the digital flight control system. These margins are normally obtained from the open-loop frequency response of systems with feedback control in an extensive postflight data reduction and analysis process. Using the old methods of envelope expansion, only one new flight condition or control system configuration could be flown each flight because a stability analysis had to be performed before proceeding to the next condition and was therefore quite time-consuming. Recent improvements in the computational capabilities of the Western Aeronautical Test Range have allowed a significant amount of flight data to be analyzed on line. Consequently, a capability to perform a frequency domain analysis of the combined airframe-flight control system using fast Fourier transform (FFT) techniques has been developed. At the same time the ability to compare the response of the airplane with that of the simulator—again while the airplane is in flight—in both the frequency and time domains was implemented.

Figure 20 depicts schematically how the open-loop frequency response is obtained from pilot-generated frequency sweeps, on line, without altering the control system structure. An actual misson control center display is in the lower right-hand corner, and an experienced flight control engineer can "read" the gain and phase margins directly from the plot; of course those margins are also displayed in digital format. The predicted response of the airplane control system combination is generated from a linearized aircraft simulation for the exact input provided by the pilot and is immediately overlayed on the plot so that near-real-time comparisons between predicted and actual response can be accomplished. The linear equations of motion are also utilized to produce time-history comparison plots in real time showing the differences between the airplane and the linearized version of the simulator (Fig. 21).

A very important side benefit has accured from the development of this capability. The inherently hazardous initial envelope clearance can proceed faster and at lower risk because the necessary information is presented to the flight test team in near-real time. Since envelope clearance was possible at several test points on the same flight, it has been estimated that the use of this on-line capability resulted in a 30 percent reduction in time required to clear the X-29 flight envelope. Furthermore, the on-line analysis eliminated the postflight data reduction requirement for stability margins.

A new real-time aeroperformance analysis technique has been developed as part of the X-29 flight research program. This ability to compute and graphically display real time aeroperformance flight results includes the calculation of the flight-derived drag polar, lift curve, and aircraft specific excess power. A key element of this new method was the concurrent development of a real-time in-flight net thrust algorithm in conjunction with Computing Devices Company of Ottawa, Canada.

The performance flight research phase of the X-29 program required the rapid acquisition and evaluation of flight data to model the aircraft lift and drag characteristics. A limited number of flights were available to completely define the aerodynamics and determine the performance potential of the forward-swept wing and its related technologies, such as the close-coupled wing-canard configuration and the wing automatic camber control mode. Dynamic flight maneuver techniques, coupled with body-mounted accelerometer measurement methods, were used to quickly define the drag polar shape and minimum drag level. Maneuver dynamic effects, instrumentation system capability, maneuver flight techniques, attainment of target flight conditions, and other factors affected the quantity—and more importantly—the quality of the flight data obtained. The real-time aeroperformance analysis capability allowed for quick, accurate, postmaneuver evaluation of maneuver technique and data quality, increasing the productivity of the flight program. Shown in Fig. 22 is a schematic of drag polar creation by a series of aircraft maneuvers. Starting from 1-g stabilized flight, a pushover-pullup maneuver was performed that reduced both the lift and the drag. This was immediately followed by a windup turn that steadily increased both lift and drag. The technique also gave an immediate postflight measure of performance for comparison with predictions or other analyses. Accuracy of the drag polars was estimated to be better than ± 2.5 percent over the entire engine power range, based on the extensive test cell calibrations of the flight engine conducted at Lewis Research Center.

The gross thrust and inlet air flow momentum, or ram drag, were computed in real time at up to 12.5 times/sec. The gross thrust algorithm calculates thrust based on a one-dimensional isentropic flow analysis in the engine afterburner section and the exhaust nozzle. The algorithm requires gas pressure measurements from three afterburner locations and includes the turbine exhaust total pressure, and the afterburner entrance and exit static pressures, as well as the free-stream static pressure. Because no additional instrumentation was required to compute ram drag, the real-time value of net thrust was computed from gross thrust minus ram drag. The resulting net thrust was corrected for the inlet spillage and nozzle propulsive drag components in real time from table look-up estimates to yield the net available propulsive force required to compute in-flight aircraft drag. A real time graphics display was also developed to display drag polars, lift curves, and specific excess power as a function of Mach number. An example of a drag polar that was computed and displayed in real time is shown in Fig. 23.

An accurate aeropropulsion analysis technique has been developed that significantly improves the productivity of the flight research team, and because it all but eliminates the requirement for extensive postflight data reduction and analysis, the transfer of flight results to the user should be increased dramatically.

FUTURE DIRECTIONS

The need for and payoff of flight research continues to be required for the advancement of aeronautical technologies. Many opportunities are looming on the horizon and promise significant breakthroughs in performance and the economics of flight. The resurgence of interest in high-speed transports (Fig. 24) has caused the identification of several technology development areas that need or would greatly benefit from flight validation. Chief among these is the development and demonstration of viable supersonic laminar flow concepts. Conceptual experiments have been defined for test on a General Dynamics F-16XL (Fig. 25) and planning for a coordinated ground and flight research program is under way. To understand and assess the effects of aerodynamic heating on laminar flow, experiments using a YF-12 aircraft as a testbed airplane are in the preliminary discussion phase. Similarly, flight demonstration of advanced propulsion concepts such as the supersonic throughflow fan and air turboramjets will require flight validation in order to reduce the risk sufficiently for commercial development.

To establish the viability of a short takeoff, vertical landing (STOVL) fighter aircraft (Fig. 26) with an acceptable weight penalty will likely require the development of an experimental or technology demonstrator aircraft. Significant advances in propulsion system and integrated control system capability are required, and validation of these advances will be required in the real and dynamic flight environment before the risk is acceptable. Strategists in the government are predicting that the military is going to need aircraft that possess supersonic dash performance, all-weather operational ability, high air-to-air agility, and short takeoff and vertical landing capability. The key to the integration and maturing of these capabilities will be the development and flight test of an aircraft.

One of the biggest challenges facing the aerospace community, if not the biggest, is the development and flight test of the X-30 hypersonic research airplane (Fig. 27). This program focuses technology development on the X-30 vehicle, which is to used to demonstrate the successful merging of aeronautical and space technologies across the speed range from takeoff to orbit velocities. There are enormous challenges in developing airbreathing propulsion systems that will provide the necessary thrust at all required speeds and altitudes. New structural materials are essential for both the engine and airframe to maintain their structural strength in extremely adverse environments. Integration of the propulsion control, flight control and thermal management systems is crucial to the operational success of this vehicle. The flight research community is faced with the development of new instrumentation, air data systems, real-time analysis techniques, ground structural test, simulation and integrated test capability, and other capabilities in order to be able to safely and efficiently conduct the X-30 flight research program. Flight research has been and will continue to be the critical link in the development, acceptance, and application of advanced aeronautical concepts.

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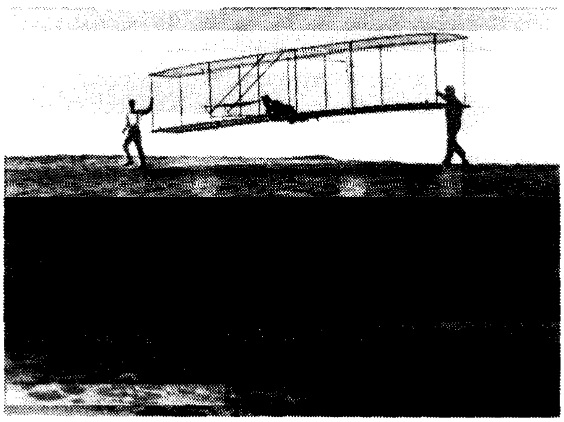

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Figure 1. Wright brothers' glider.

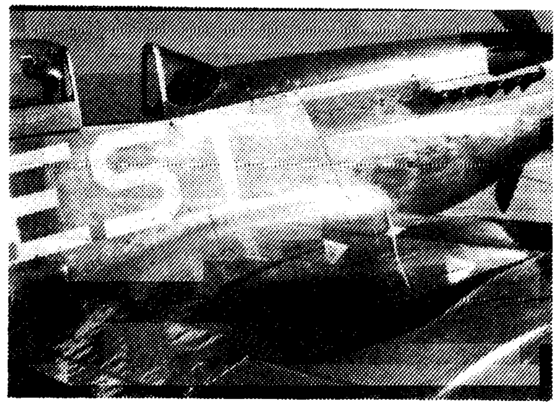

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Figure 2. P-51 wing with model.

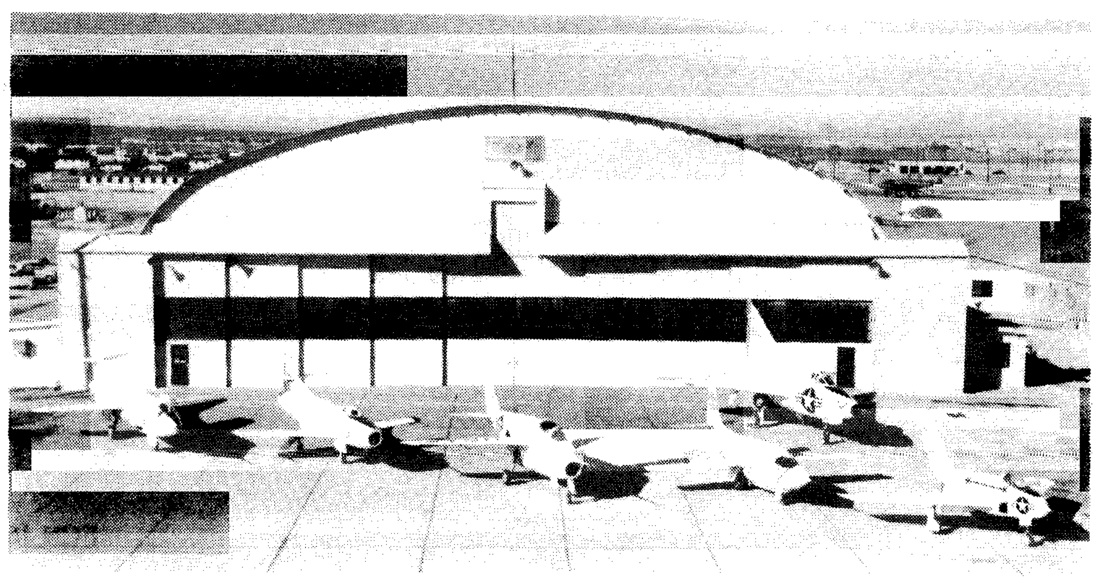

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Figure 3. X airplanes.

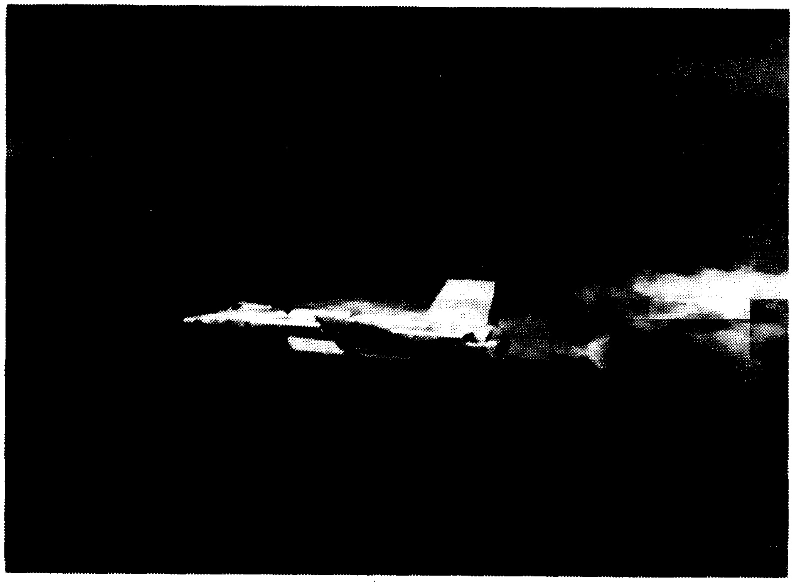

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Figure 4. X-15.

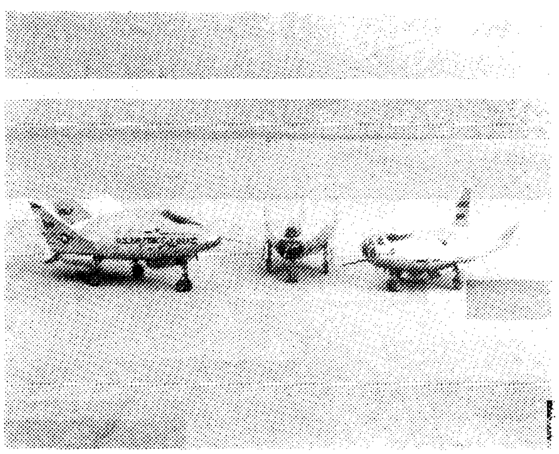

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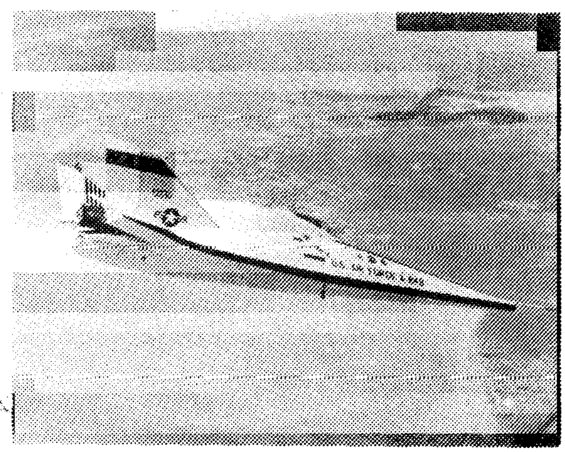
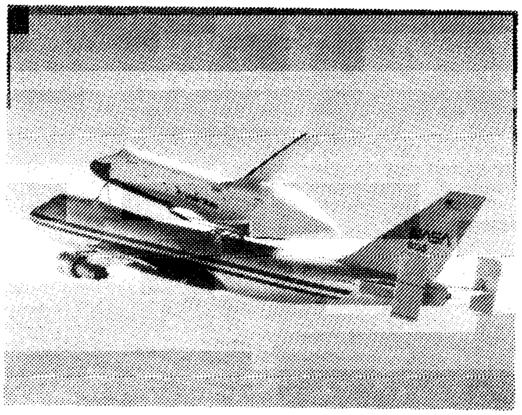
Figure 5. M-2, HL-10, and X-24A.



ECN 4642

Figure 6. X-24B.



ECN 77 06879
Figure 7. 747 with shuttle.

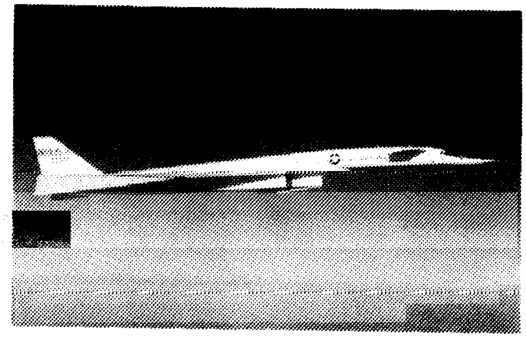


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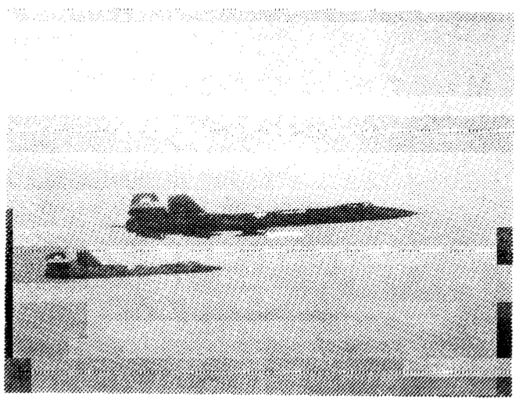
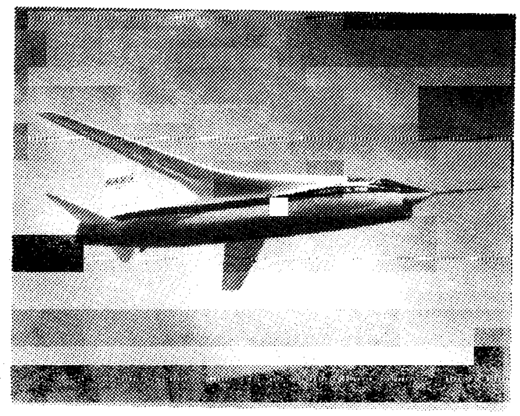
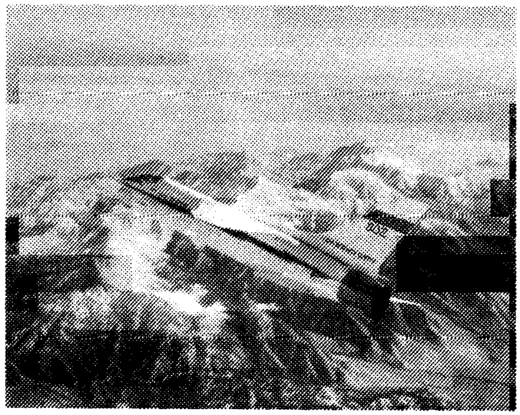
Figure 8. XB-70.



ECN 75 4769
Figure 9. YF-12 aircraft.



EC 73 3468
Figure 10. F-8 supercritical wing.



ECN 3478

Figure 11. F-8 digital fly-by-wire.

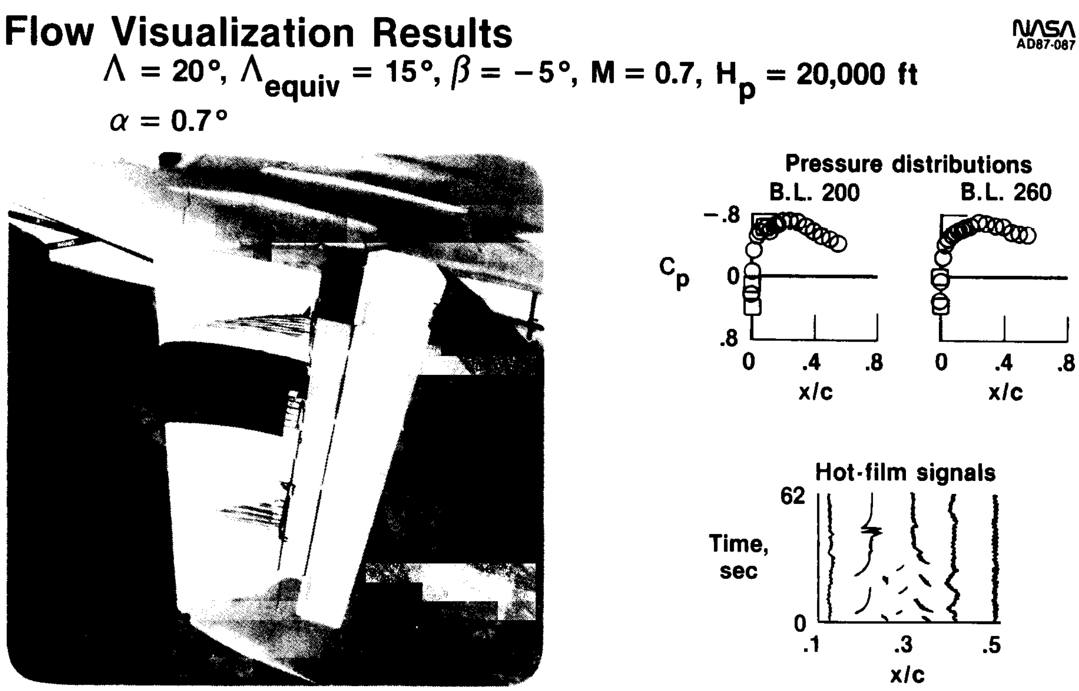
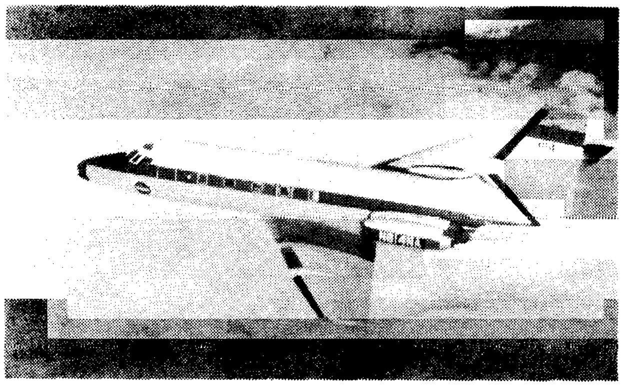
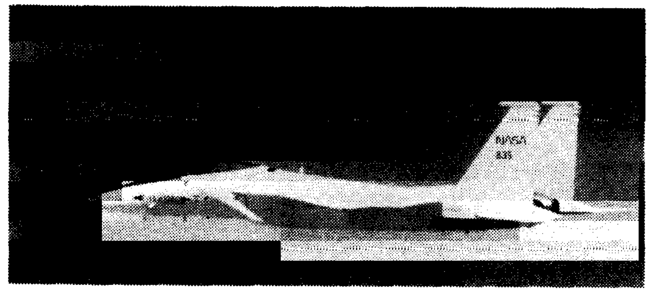


Figure 12. F-14 flow visualization with liquid crystals.



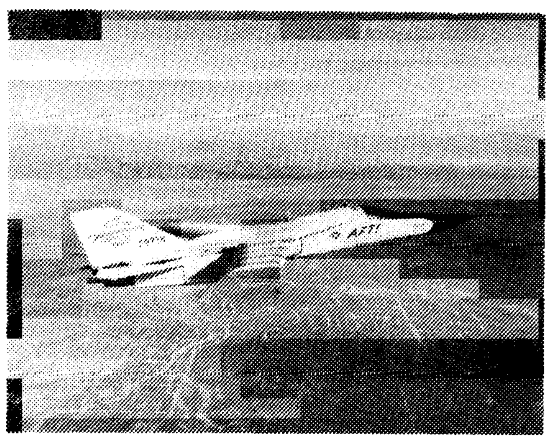
EC83 27177

Figure 13. JetStar.



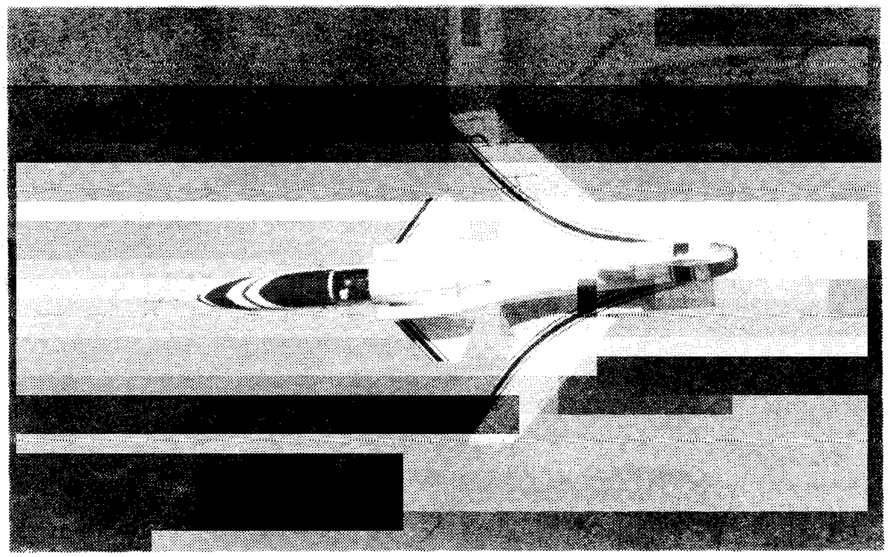
EC 86 3344 003

Figure 14. HIDEC airplane.



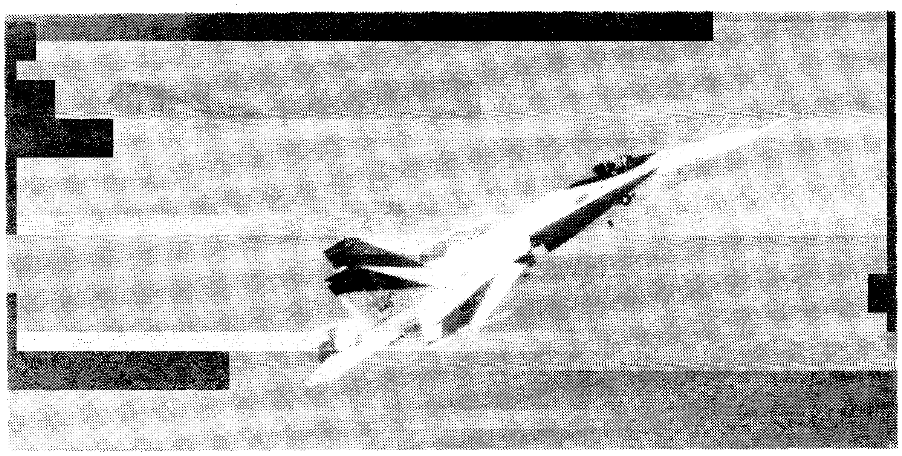
EC 86 33385 002

Figure 15. Advanced fighter technology integration (AFTI)/F-111.



EC 0182 017

Figure 16. X-29.



EC87 0161 001

Figure 17. F-18 at high alpha.

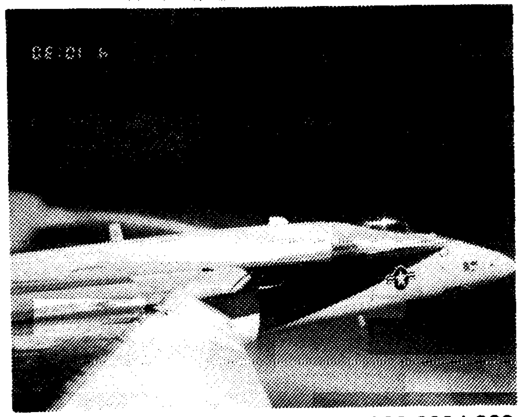


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Figure 18. F-18 vortex.

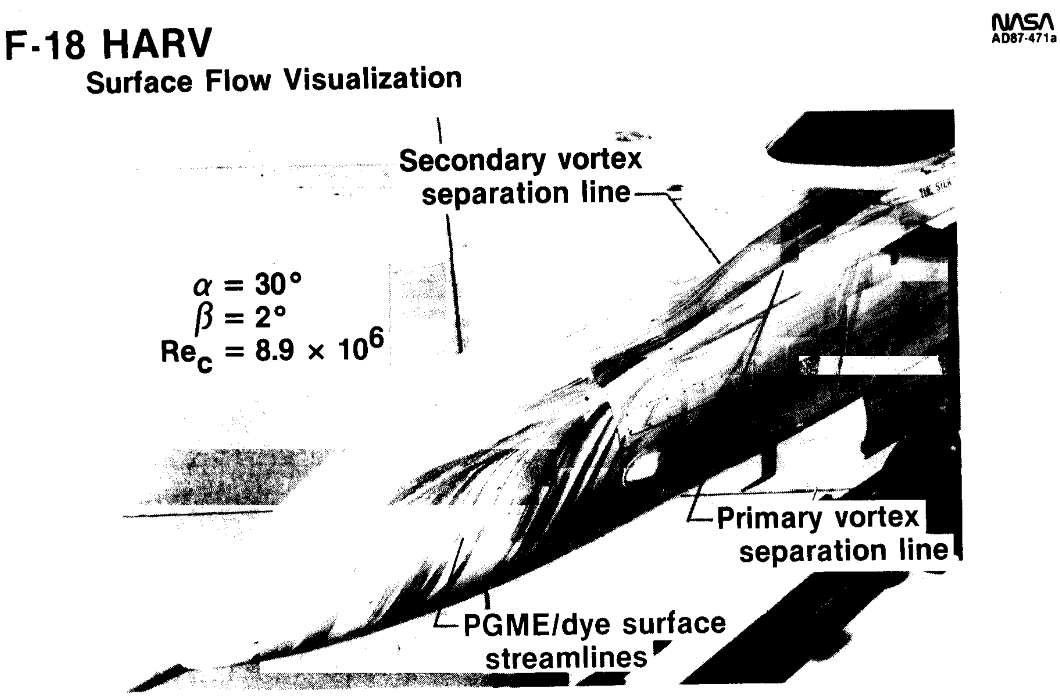


Figure 19. PGME patterns on F-18.

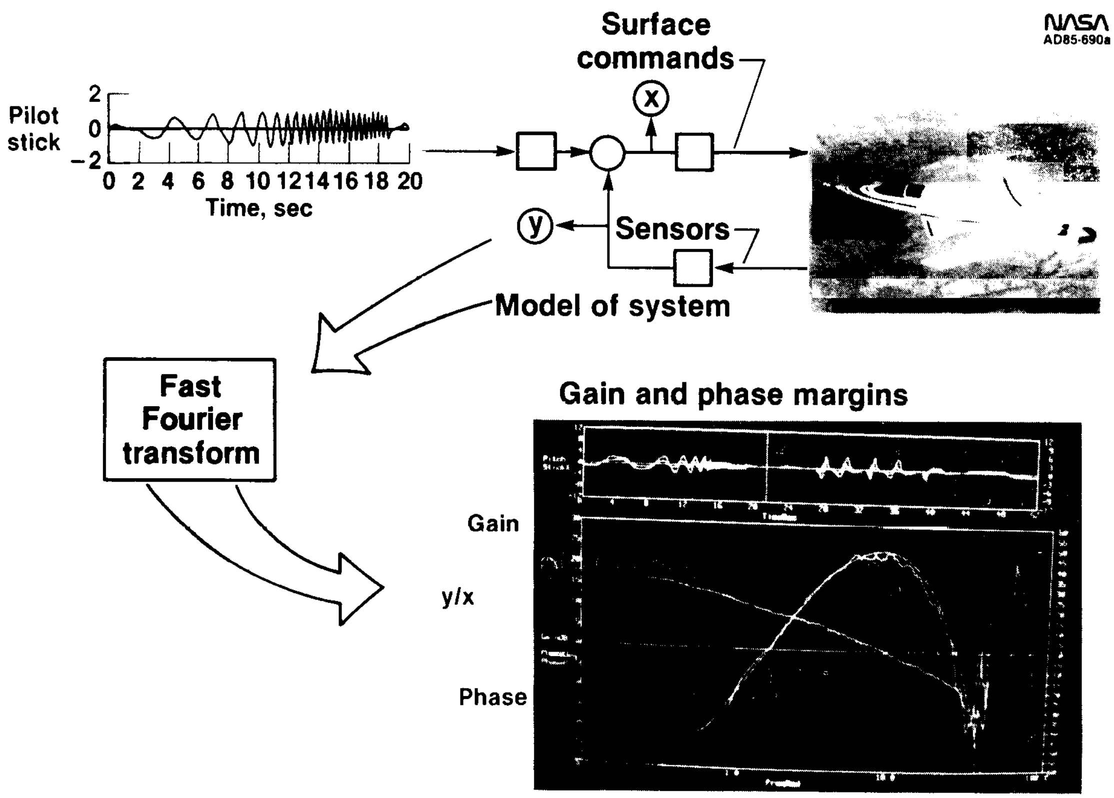


Figure 20. Flight-determined frequency response for unstable airframes.

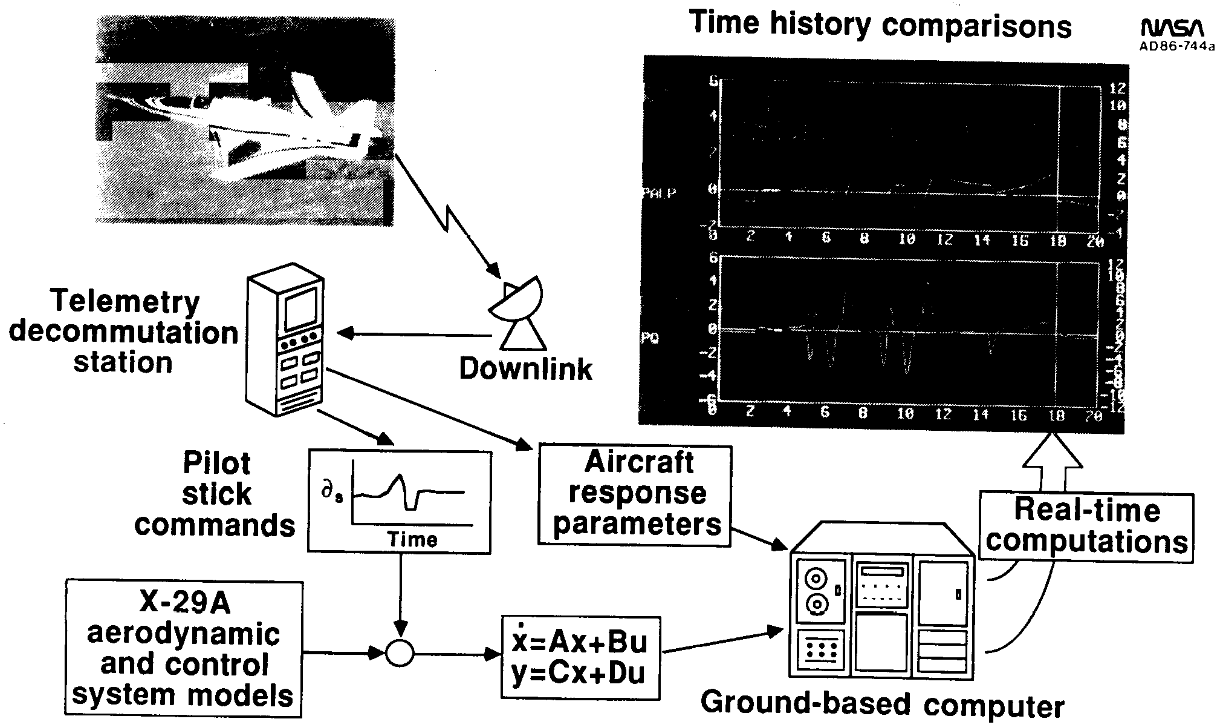
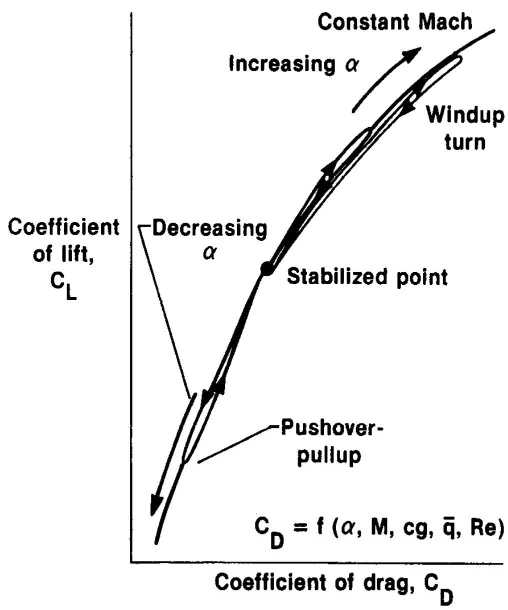


Figure 21. Real-time comparison of linear simulation to flight.

Flight Test Approach

NASA AD86-1021



- Maneuvers flown to obtain polar shapes
  - –Dynamic maneuvers
  - –Maneuvers sweep alpha range
- Maneuvers
  - –Pushover-pullup
    - 0- to 2-g maneuver
    - Covers lower to medium alpha range
  - –Constant thrust windup turn
    - 1 g to target N_z
    - Covers medium to high alpha range

Figure 22. Flight test manuevers for drag polar creation.

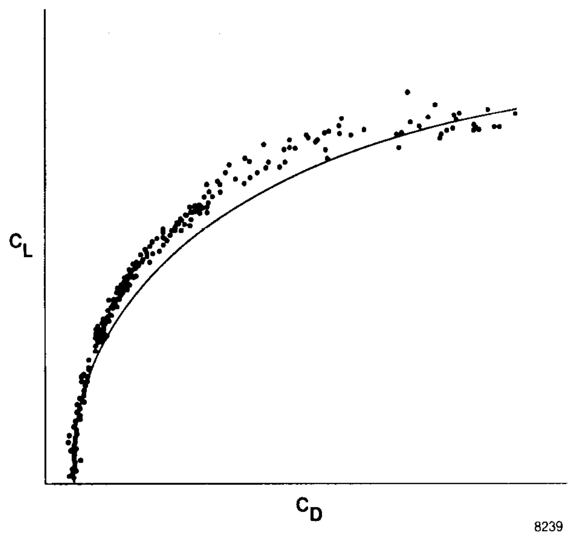
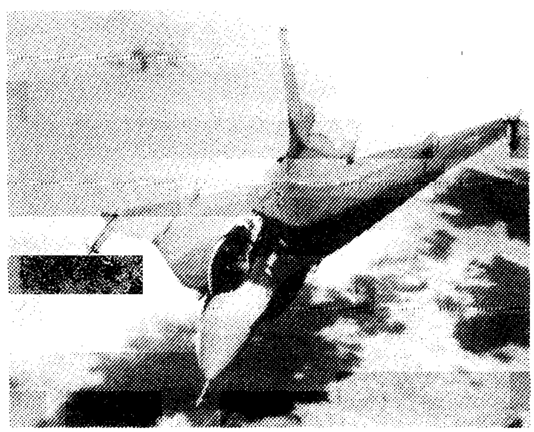


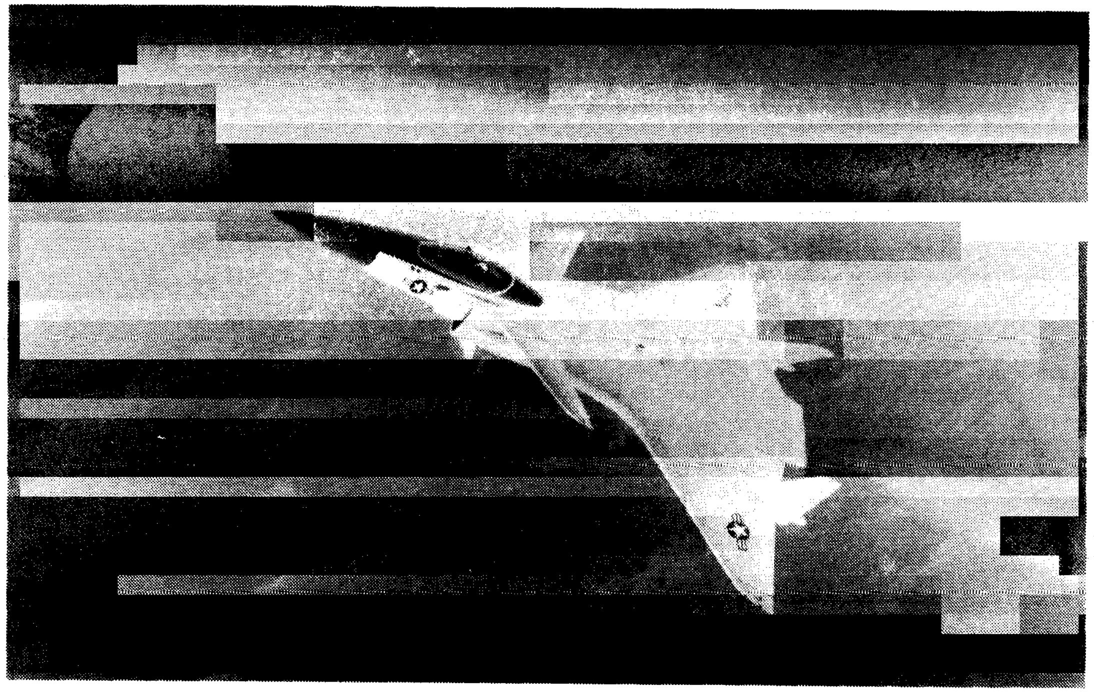
Figure 23. X-29 real-time drag polar.

Figure 24. Drawing of high-speed transport.



EC87 0261 001

Figure 25. F-16XL.



EC88 0071 001

Figure 26. Conceptual STOVL fighter.

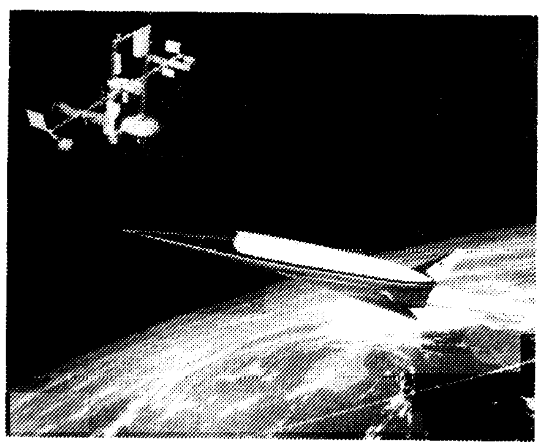


Figure 27. National aerospace plane (NASP).

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16. Abstract

Flight research and flight testing form a critical link in the aeronautics research and development chain. Brilliant concepts, elegant theories, and even sophisticated ground tests of flight vehicles are not sufficient to prove beyond a reasonable doubt that an unproven aeronautical concept will actually work and perform as predicted. Flight research and testing provide the ultimate proof that an idea or concept performs as expected. Ever since the Wright brothers, flight research and testing have been the crucible in which aeronautical concepts have advanced and been proven to the point that engineers and companies have been willing to stake their future to design and produce new aircraft. That is still true today, as shown by the development of the experimental X-30 aerospace plane.

The Dryden Flight Research Facility of NASA Ames Research Center (Ames-Dryden) continues to be involved in a number of flight research programs that require understanding and characterization of the total airplane in all the aeronautical disciplines, for example the X-29. Other programs such as the F-14 variable-sweep transition flight experiment have focused on a single concept or discipline. Ames-Dryden also continues to conduct flight and ground-based experiments to improve and expand the ability to test and evaluate advanced aeronautical concepts. A review of significant aeronautical flight research programs and experiments is presented here to illustrate both the progress being made and the challenges to come.

17. Key Words (Suggested by Author(s))
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